AIMAC collaboration

Research and Development for Accuracy Improvement of Neutron Nuclear Data on Minor ACtinides

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Present study includes the result of “Research and Development for accuracy improvement of neutron nuclear data on minor actinides” entrusted to the Japan Atomic Energy Agency by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).

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- Needs and Recent Situation of MA data
- Aim, Actions, Approach of the AIMAC
- Highlights of the AIMAC

    Details
    S033, S055, S111, S114, R130, S185, R300, S301

- Conclusions and Future Perspective

Needs of accurate nuclear data of MA for nuclear transmutation technology

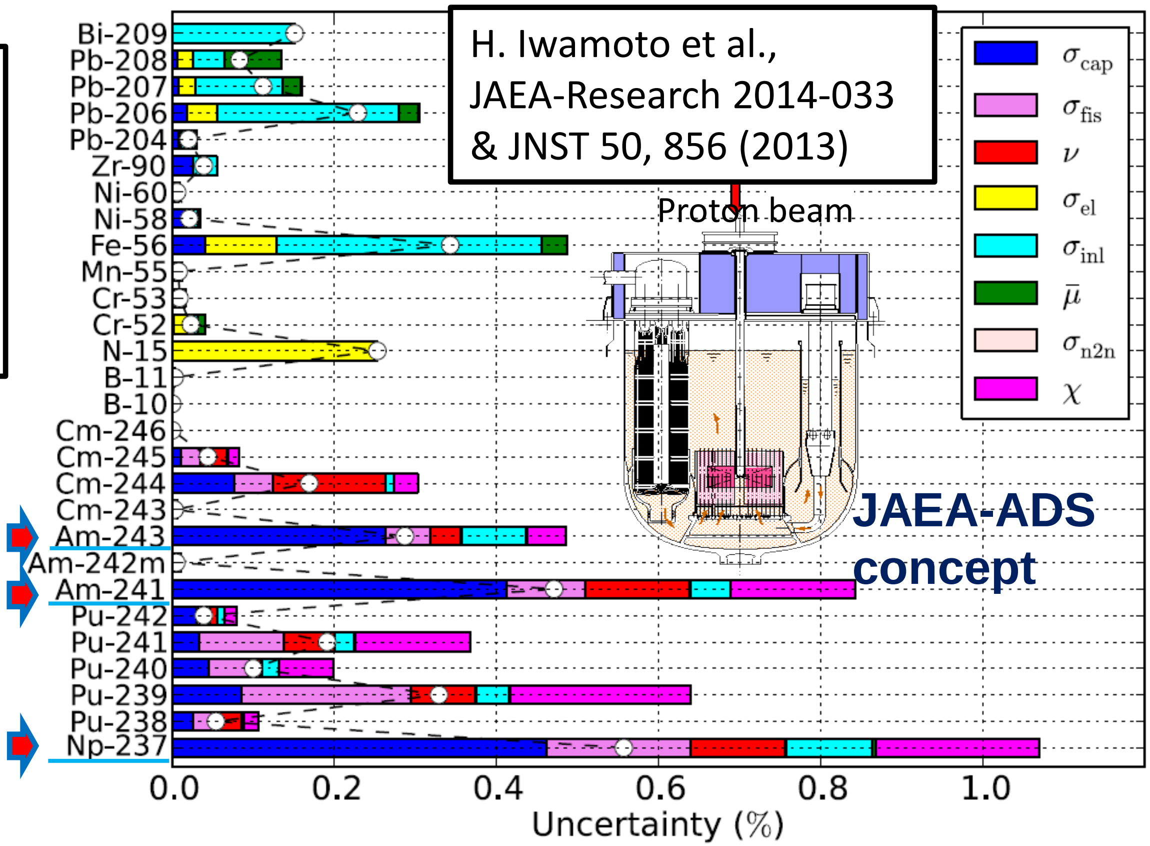
Example:

Uncertainty analysis on JAEA-ADS Criticality dk with Covariance of JENDL-4.0

$$\frac{dk}{k} = 1.0\%$$

$$1 + k + k^2 + \ldots = \frac{1}{1 - k}$$

$k = 0.95$	20
$k = 0.96$	25
$k = 0.97$	33
$k = 0.98$	50
$k = 0.99$	100



Accuracy improvement of Capture of Am-241, Am-243, Np-237 Significant impact!

Recent situation on MA capture

Evaluation	^{241}Am thermal neutron capture cross section
JEFF-3.1.2 → JEFF-3.2	647 → 748 b
ENDF/B IV → VII.0 → VII.1	582 → 619 → 684 b
JENDL-2 → 3.3 → 4.0	600 → 640 → 684 b

Important progress presented at ND2013 on ^{241}Am capture.

Good Energy Dependence
Bias due to Westcott factor
Impact of Transmission data
Cold neutron beam data
・**Still problem on Absolute**

Int. Nuclear Data Project
OECD/NEA/WPEC/SG-41
(**INDA**) Dr. G. Žerovnik **R119**

Japanese Nuclear Data Project
AIMAC ^{237}Np, ^{241,243}Am
S033, S055, S111, S114, R130, S185, R300, S301

The others also n_TOF …

Aim and Actions of AIMAC

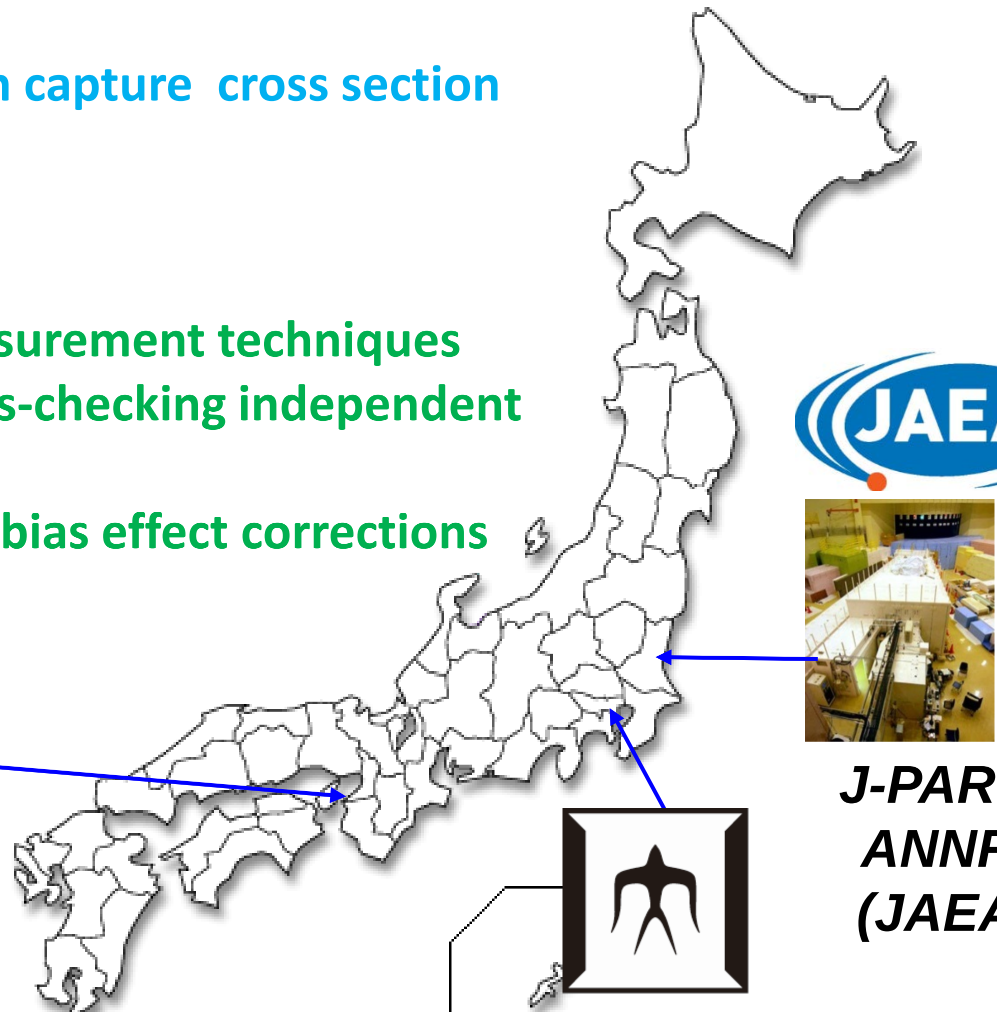
Japanese national nuclear data project
October 2013 – March 2017

Aim of AIMAC:

Improve accuracy two times on capture cross section of Am-241, Am-243, Np-237

Actions of AIMAC:

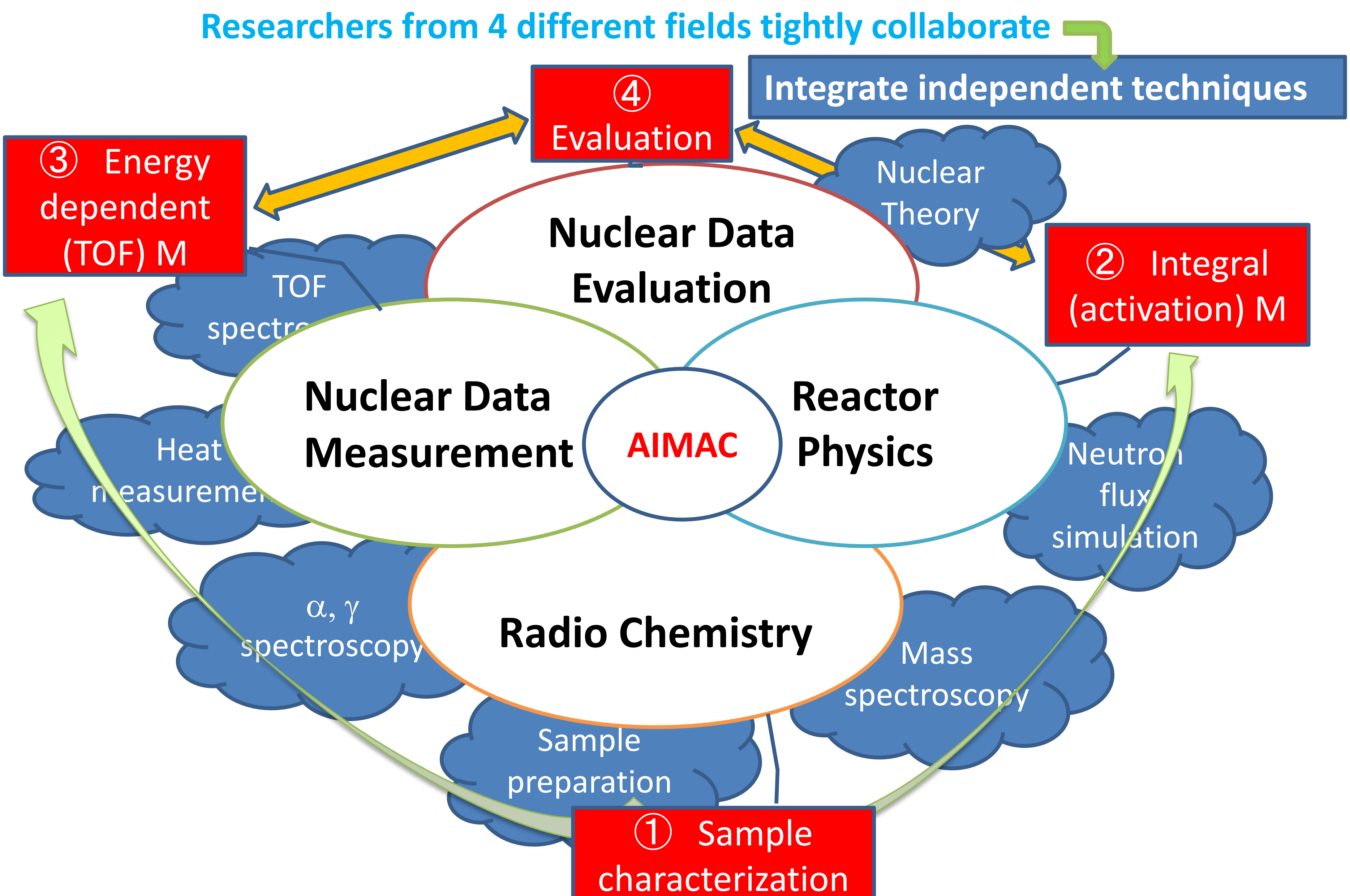
- **Develop plural precise measurement techniques**
- **Identify bias effects by cross-checking independent measurements**
- **Systematic evaluation with bias effect corrections**



J-PARC-ANNRI (JAEA)

Tokyo Tech

AIMAC approach



Highlights of the AIMAC

① Precise characterization of sample
② Activation measurement
③ TOF measurement
④ Evaluation and Bias effect Correction

① Precise characterization of sample

- For isotopic purity characterization -

The same materials with TOF samples were prepared for destructive analyses: Mass (TIMS) and α-ray spectroscopy

Sample for analyses

The Same Sample material

A few hundred MBq

TOF sealed sample

Info in specification sheets:

No uncertainty information

Am-241 sample (130 kBq/mL)

    Isotopic purity: Am-241：99.9%

    Chemical purity: 99.9%（Pu-239：0.09%, Np-237：0.01%）

Am-243 sample (10 kBq/mL）

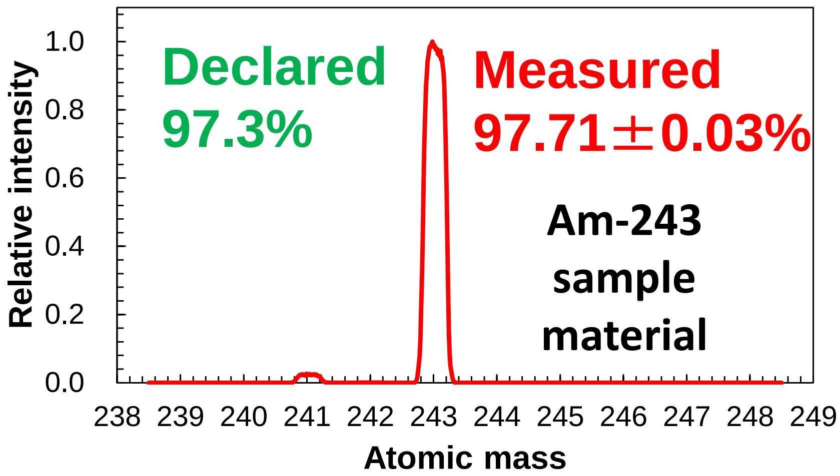
    Isotopic purity: Am-243：97.3%, Am-241：2.7%

    Chemical purity: 99.58%

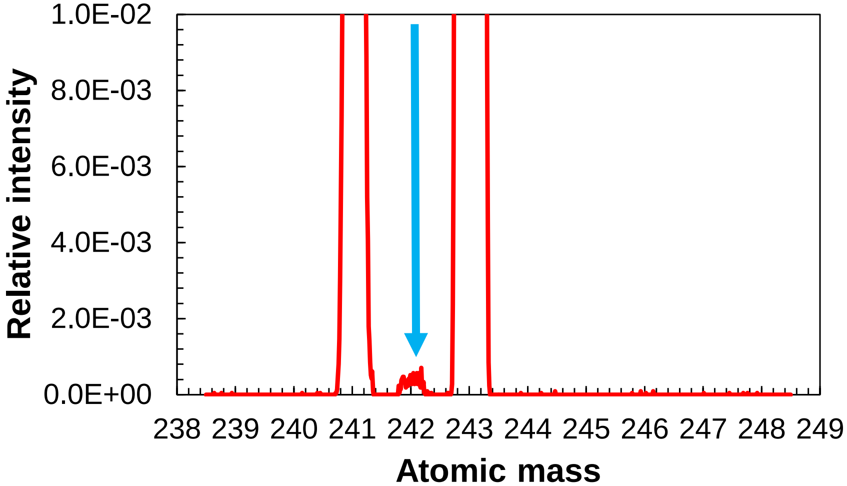
    （Fe, Ca, Na：0.07%, B: 0.09%, Gd: 0.03%etc）

① Precise characterization of sample

Thermal ionization mass spectroscopy (TIMS)



Am-242m/Am-243 = 0.039±0.006%



	Am-241	Am-243
Run-1	2.29±0.03%	97.71±0.03%
Run-2	2.28±0.03%	97.72±0.03%
Run-3	2.29±0.05%	97.71±0.05%

Non-declared isotope was identified.

Note: Pu contamination under investigation

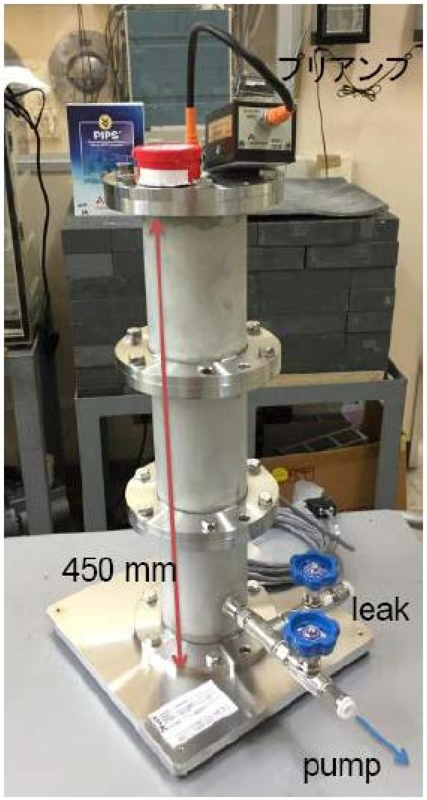
Ref: Y. Shibahara, J. Radioanal. Nucl. Chem. 307, 2281 (2016)

Details S301 by Dr. Y. Shibahara

0.03% precision !

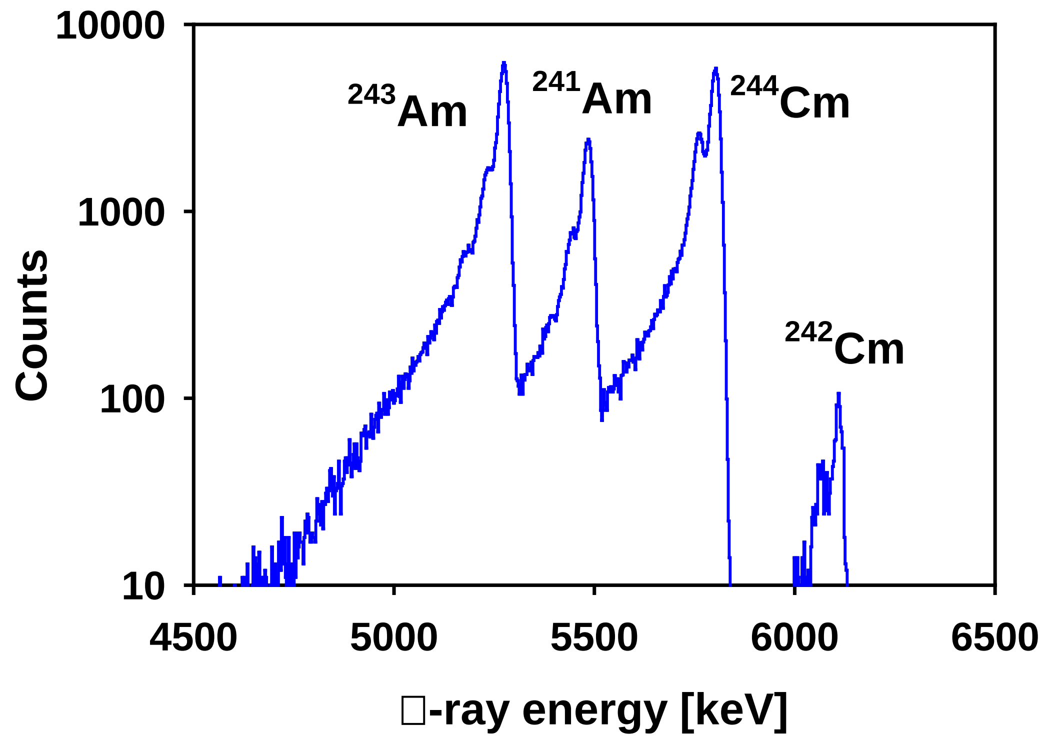
① Precise characterization of sample

α-ray spectroscopy



Setup for α-ray spectroscopy

α-ray from **Am-243** sample material



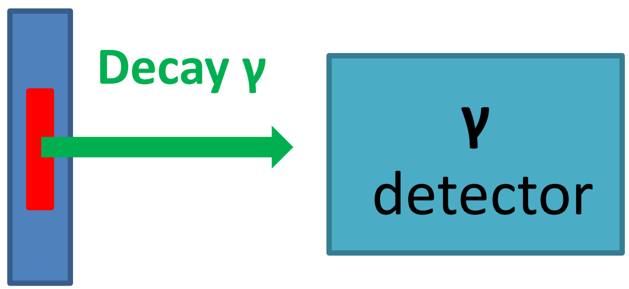
Cm-242&244 quantified

Feedback to Micro Calorimetry

① Precise characterization of sample

No uncertainty information for sealed sample amounts
(decay γ-ray rate is given by 10% uncertainty)
Two non-destructive methods developed

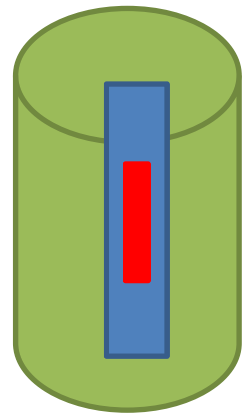
① Determination of decay γ-ray intensity

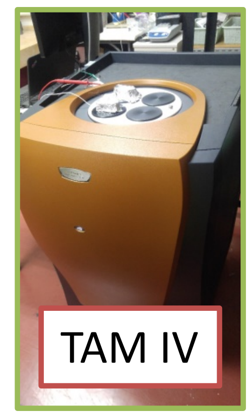


Precise determination of γ-detector's peak efficiency
Fine interpolation method was developed by utilizing Monte Carlo

Precise determination of γ-ray emission probability

② Utilization of Micro Calorimetry





Independent amounts
Cross-check

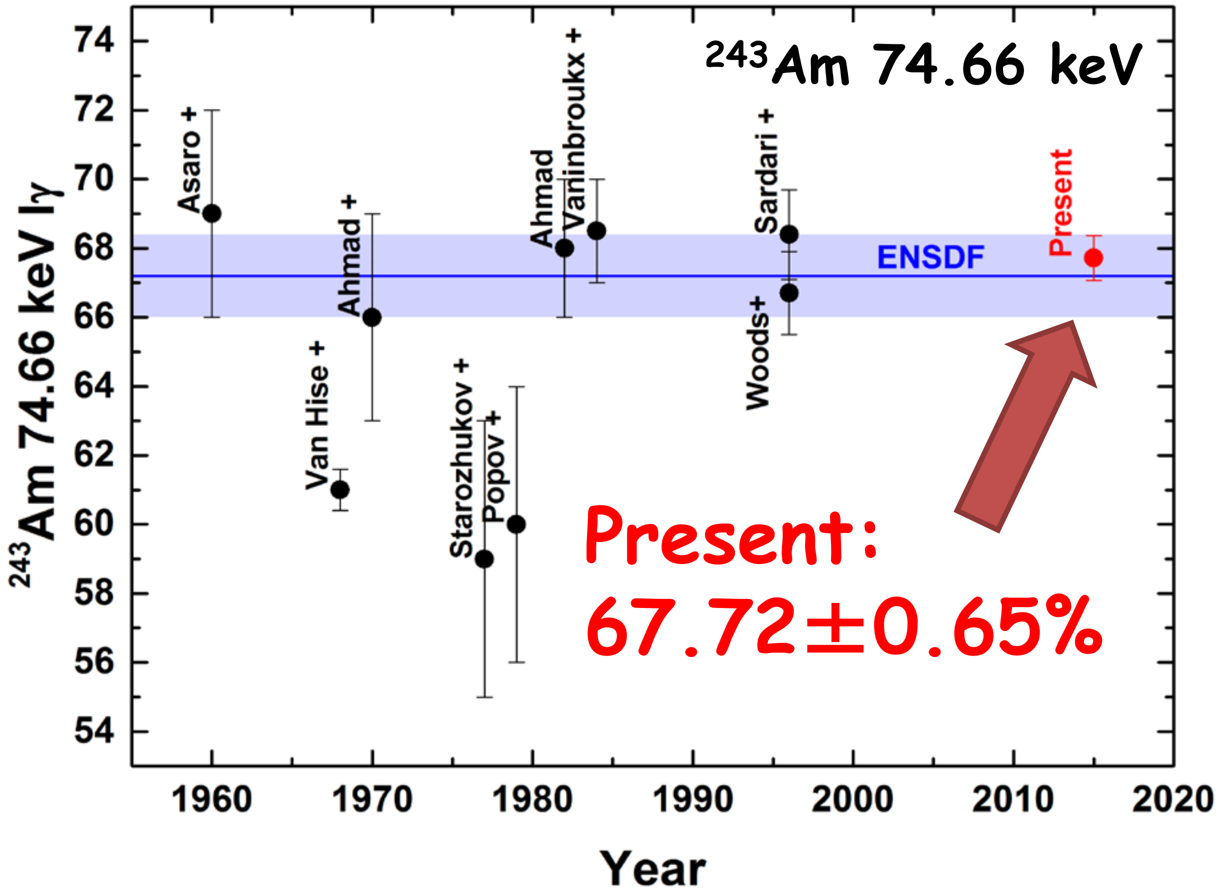
① Precise characterization of sample

- Precise determination of γ-ray emission probability -

Precise determination of γ-detector's peak efficiency

Fine interpolation method was developed by utilizing Monte Carlo

Dr. K. Terada, *J. Nucl. Sci. Technol.* **53** (2016)



① Precise characterization of sample

Comparison of two independent measurements

Declared Activity	Am-241 480 MBq	Am-241 950 MBq	Am-243 60 MBq	Am-243 120 MBq	Am-243 240 MBq
γ-ray Spectroscopy	511±10	962±19	66.7±1.3	155±3	286±6
Micro Calorimetry	510.7±0.5	957.4±0.5	67.3±0.3*	155.8±0.3*	281.8±0.3*

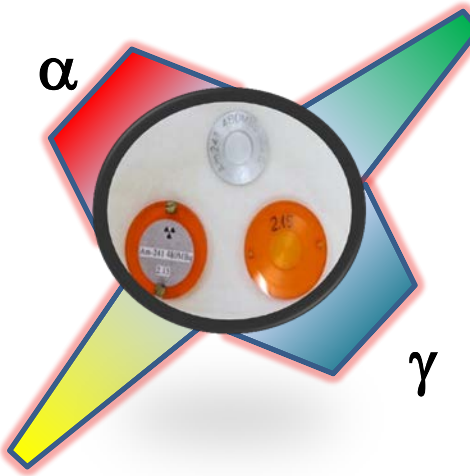
2% uncertainty

0.1% uncertainty

* Pu correction: small but to be checked

Cross-check, OK
Discrepancy between
Declared and Measured

Details R300 by
Dr. K. Terada

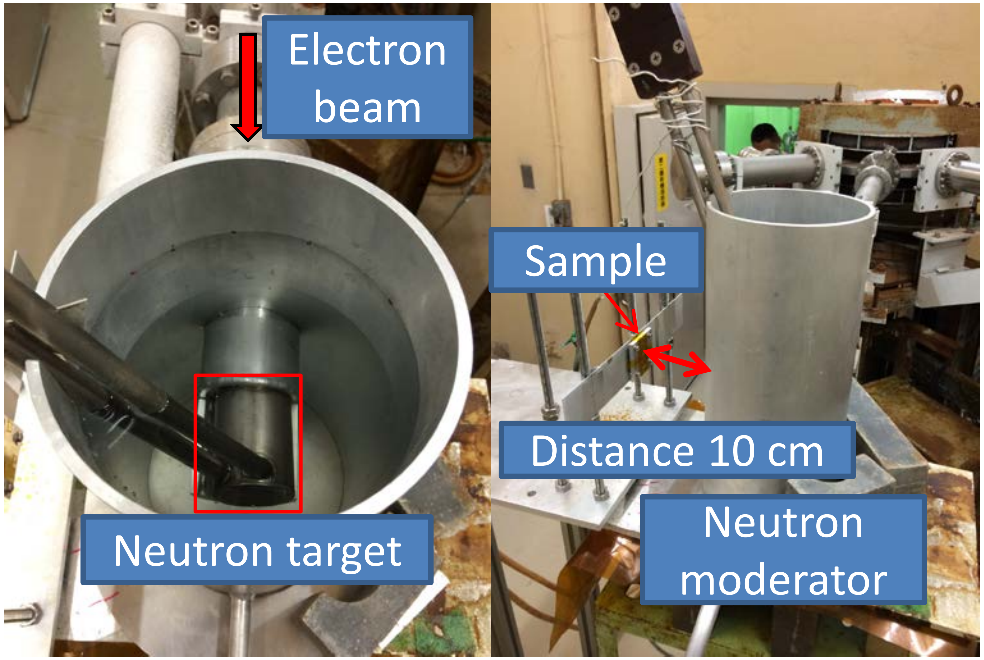


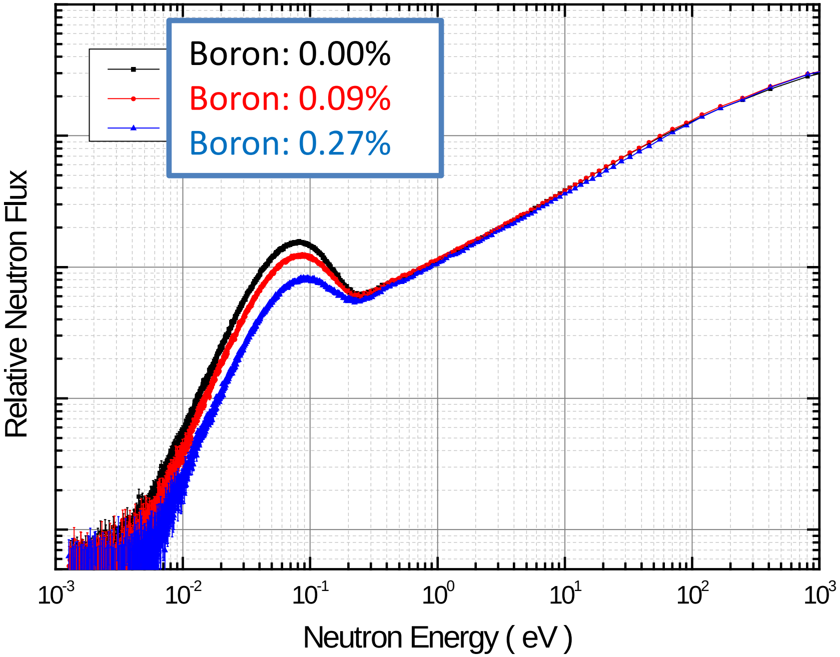
Effectiveness of integrating independent methods
α&γ ray spectroscopy,
Micro Calorimetry,
Mass spectroscopy

② Activation measurement method at Kyoto TOF facility

KURRI-LINAC

Development of variable neutron flux field for activation measurements at pulsed neutron facility



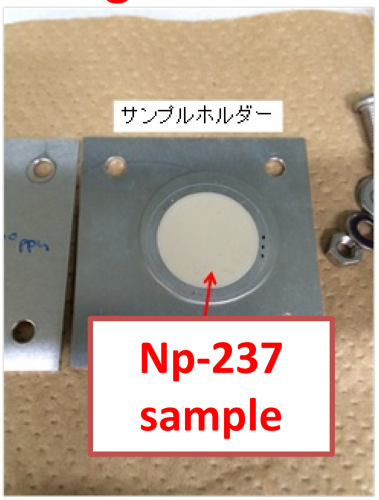


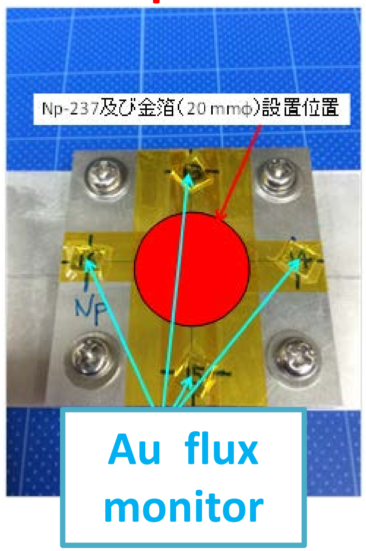
Advantage:
E dependence of neutron flux by TOF method
Variable thermal and epi-thermal flux ratio

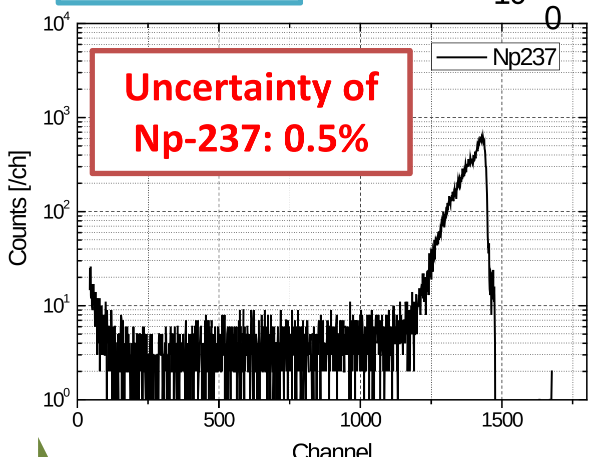
② Activation measurement method at Kyoto TOF facility

Advantage:

Usage of Unsealed Sample

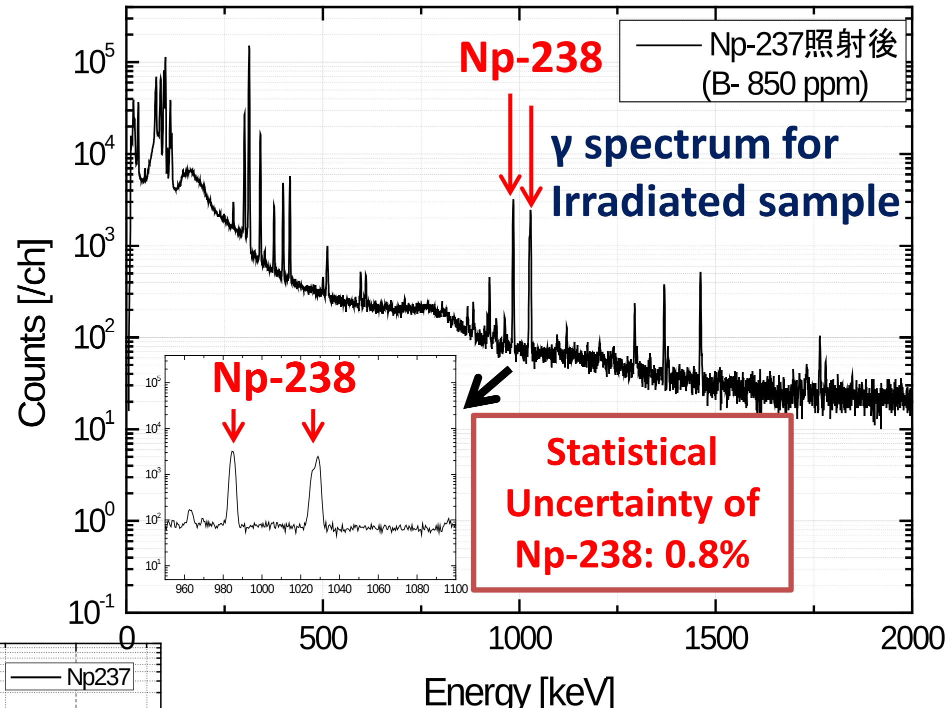






α spectroscopy → **Sample amount**

Statistics?



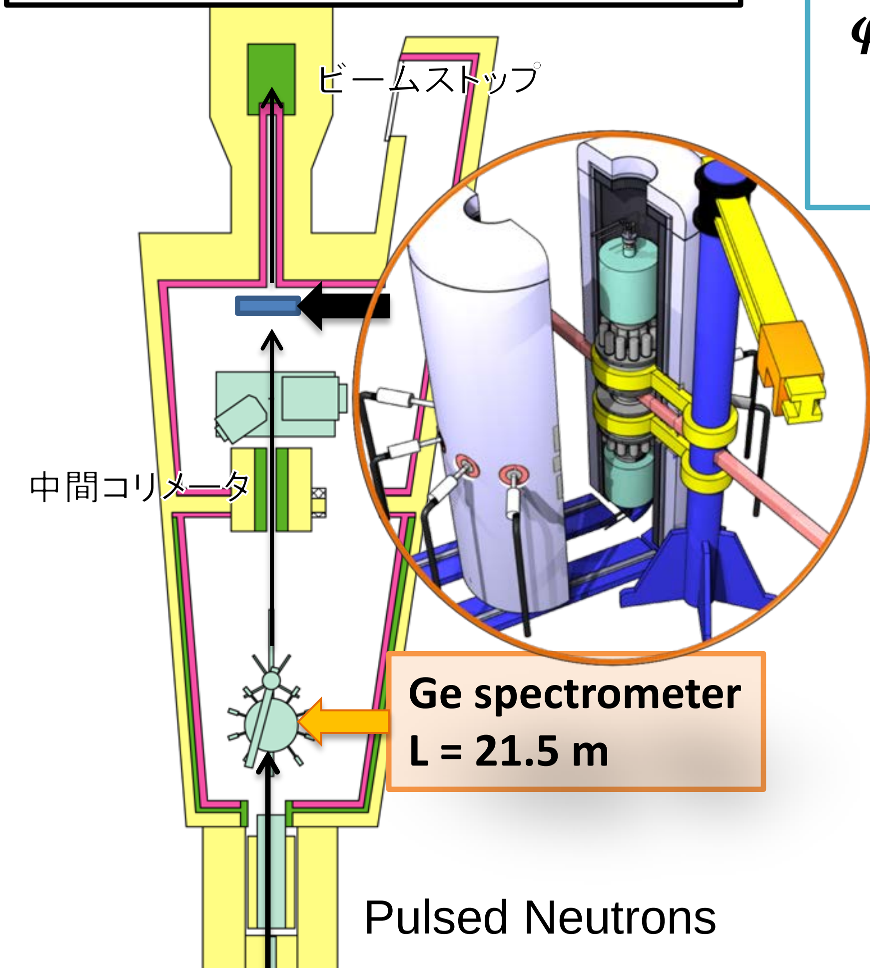
Flux averaged cross section

$$\int \phi(E)\sigma_r(E)dE$$

Details by Dr. H. Yashima (Y. Takahashi) (S033)

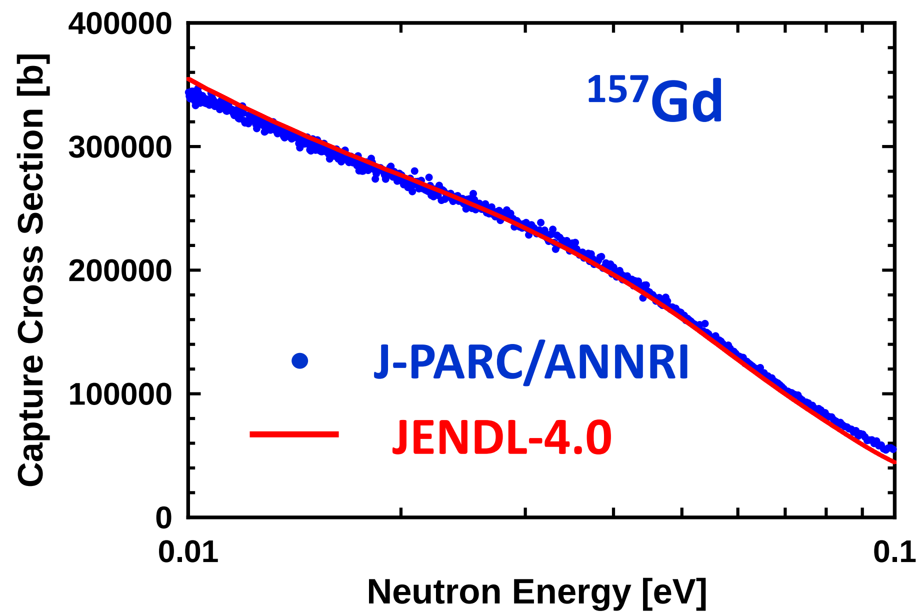
③-1 TOF measurement at J-PARC/ANNRI

A precise absolute value determination method using different thickness samples by Dr. A. Kimura **Gd-155, 157**



Ratio of Capture yields expressed in the case $\sigma_{cap} ≒ \sigma_{tot}$

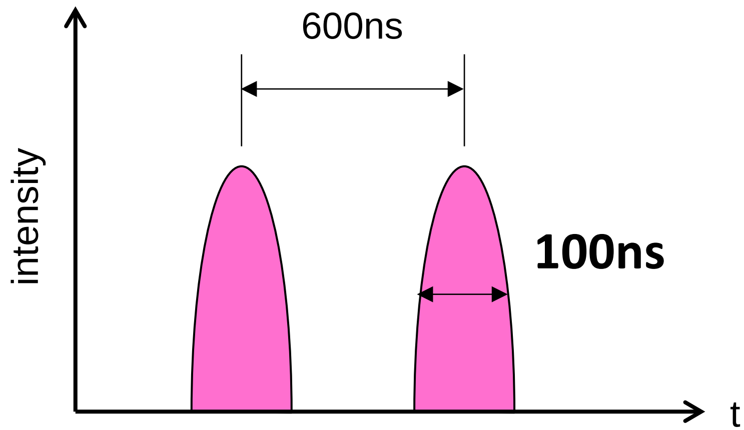
$$\frac{\varphi(E_n)\times k_{Gd}\times\left(1-exp(-\sigma(E_n)N_{thin})\right)}{\varphi(E_n)\times k_{Gd}\times\left(1-exp(-\sigma(E_n)N_{thick})\right)}=\frac{1-exp(-\sigma(E_n)N_{thin})}{1-exp(-\sigma(E_n)N_{thick})}$$

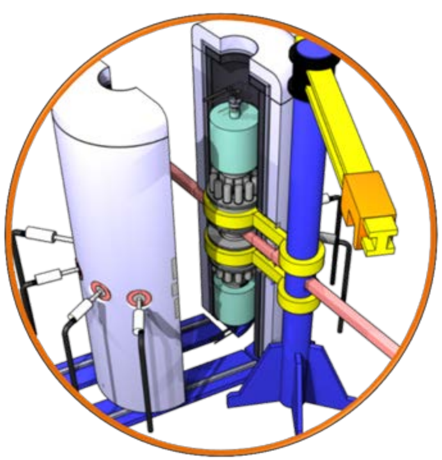


Details on resonance analyses by Dr. K. Mizuyama (S114)

③-2 TOF measurement at J-PARC/ANNRI

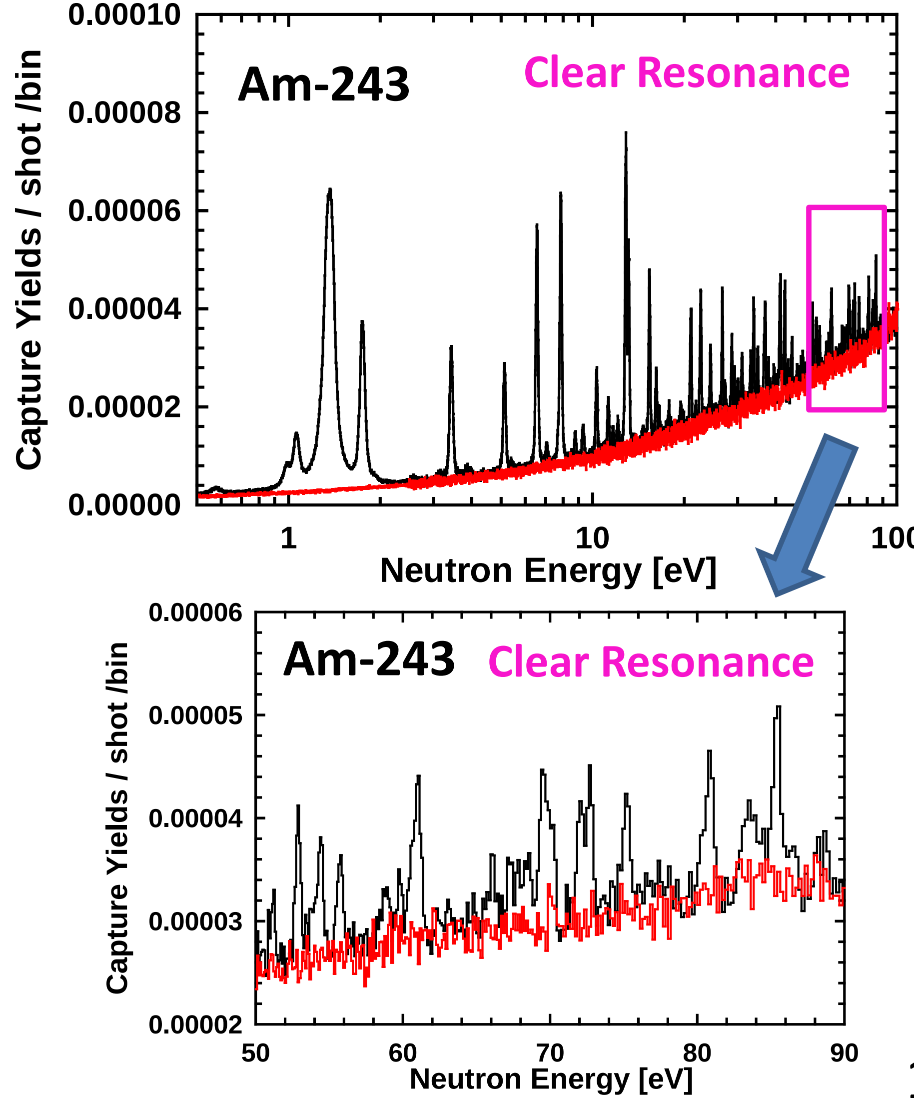
J-PARC/ANNRI High Intensity Beam
Double pulse >> Single pulse





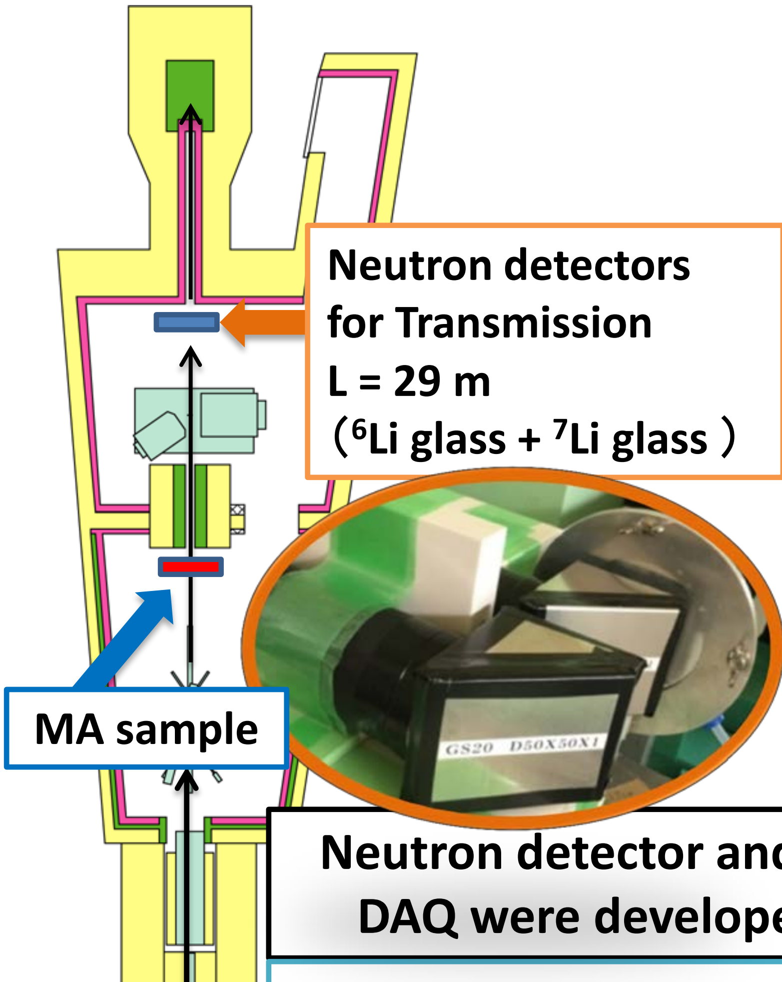
Ge spectrometer at ANNRI

Single Pulse TOF Data at ANNRI



③-3 TOF measurement at J-PARC/ANNRI

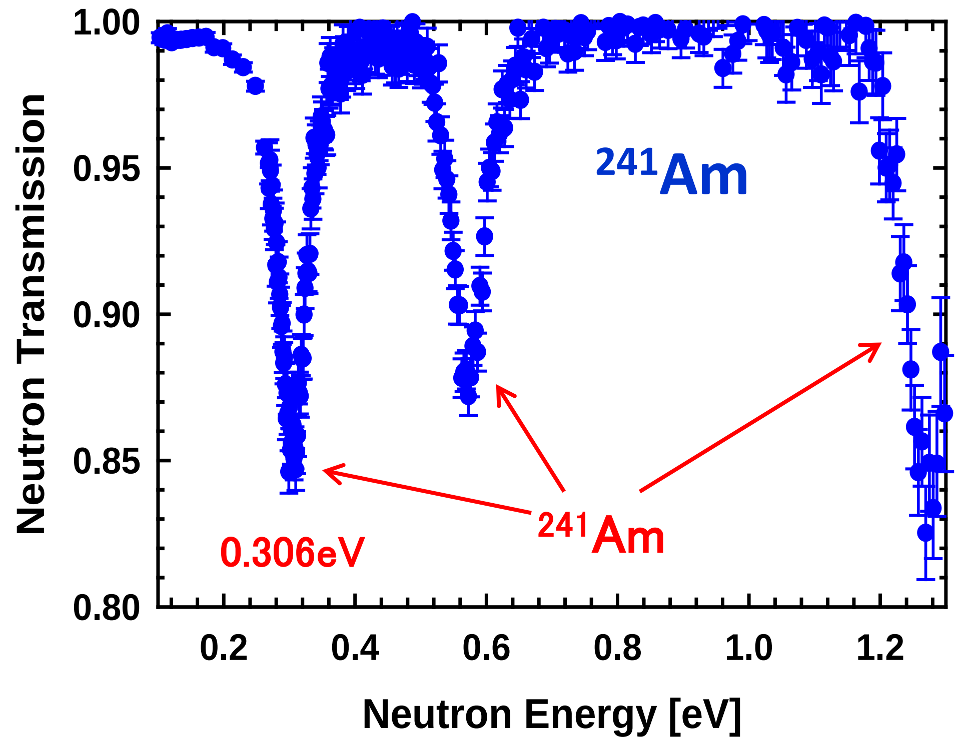
Development of tools for total cross section measurement



Neutron detector and its DAQ were developed

Details by Dr. T. Nakao (R130)

The first transmission data of MA at ANNRI

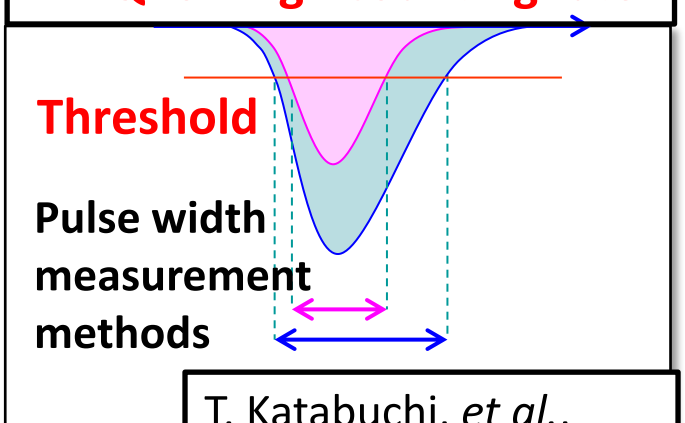


Useful info for capture determination in case Total ～ Capture

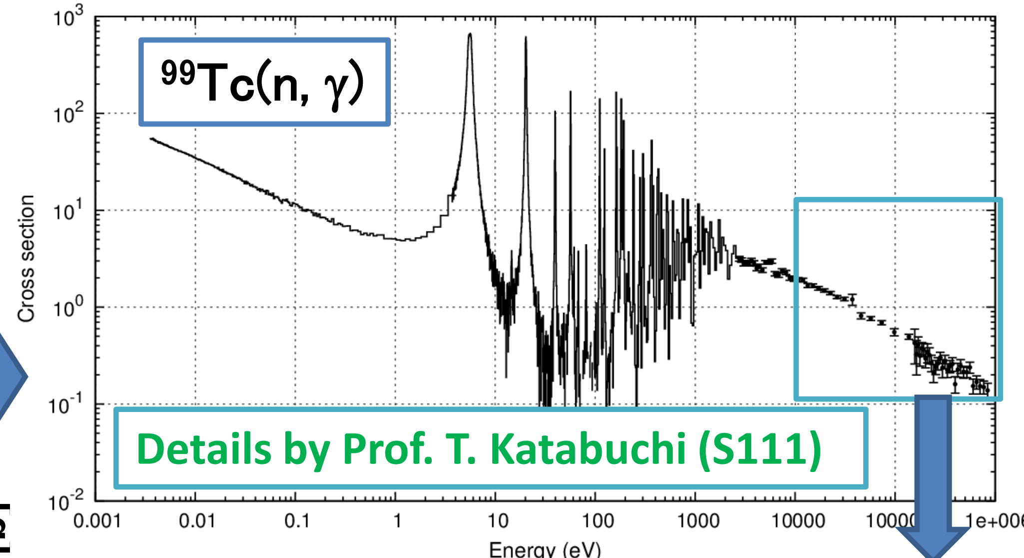
③-4 Extension of measurable energy region from 100 keV at J-PARC/ANNRI

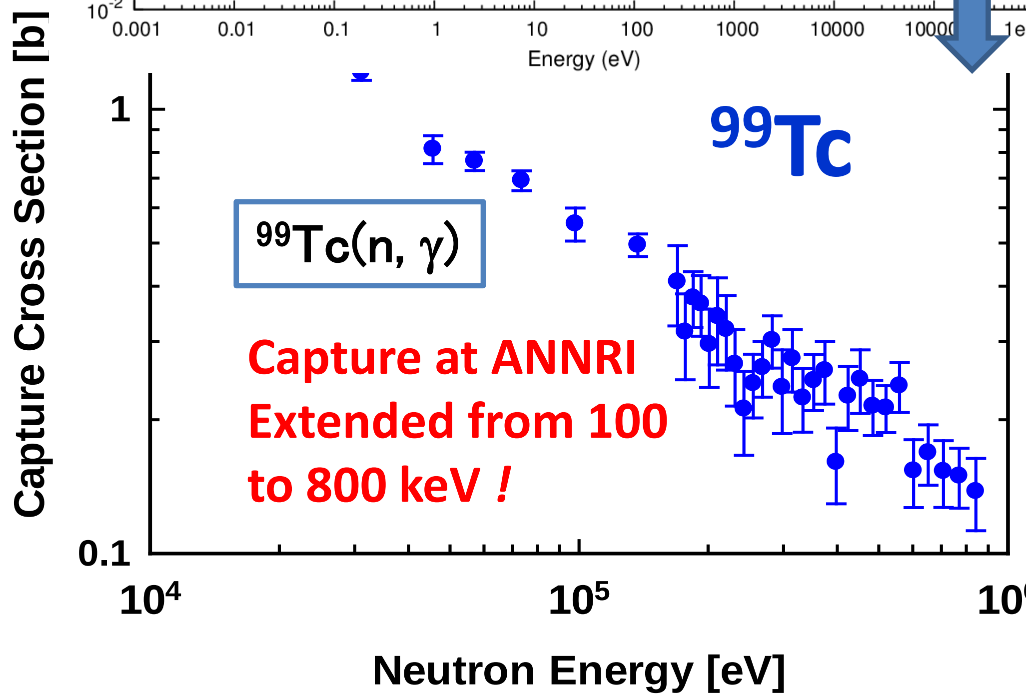
ANNRI–NaI(Tl) spectrometer

DAQ for High counting rate



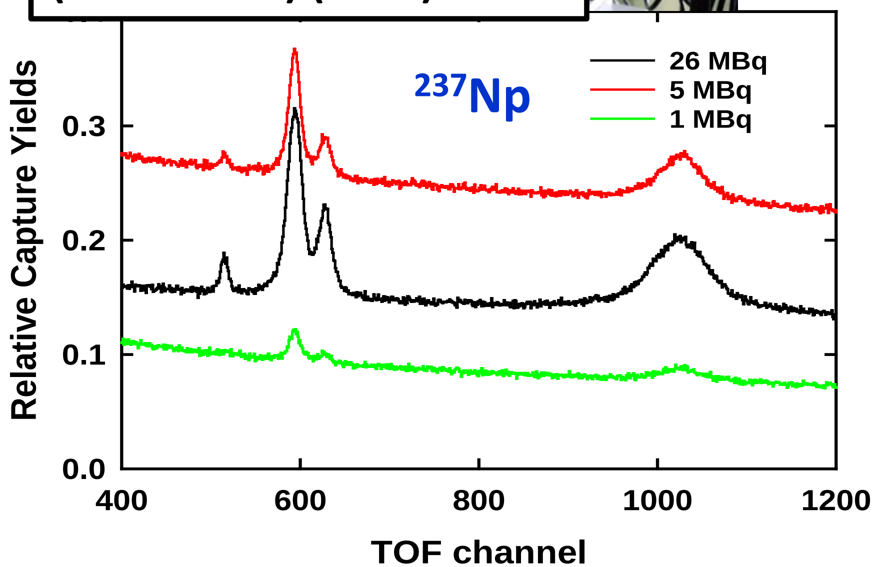
T. Katabuchi, *et al.*, NIM A**764**, 369(2014)





③-5 TOF measurement at KURRI LINAC

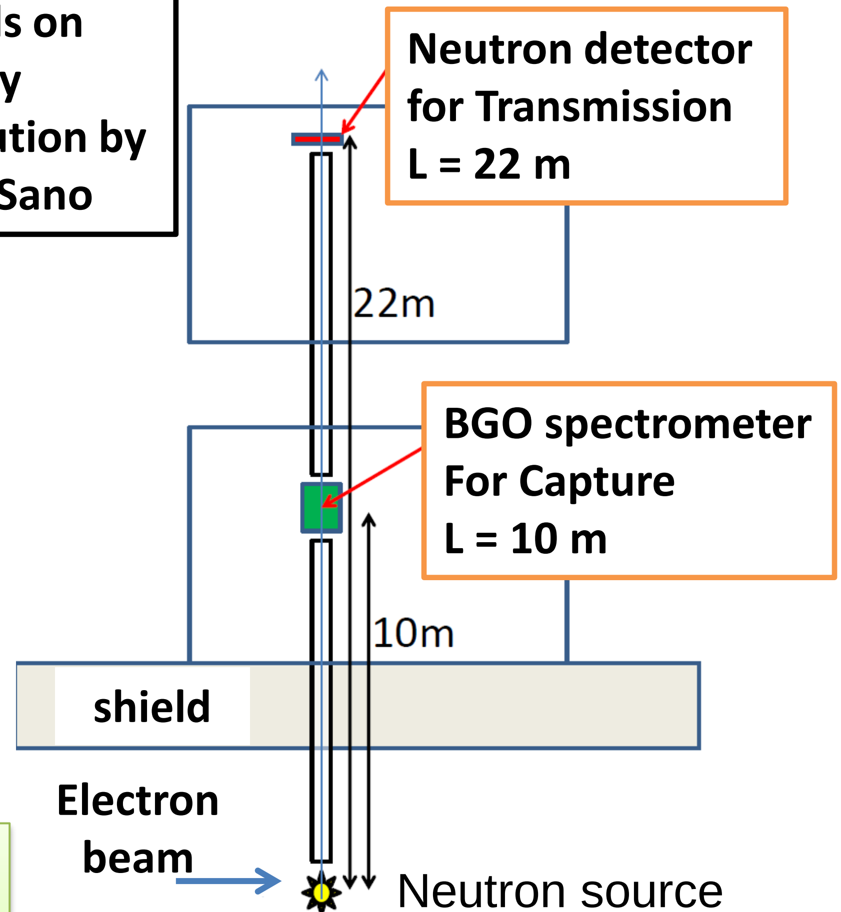
Details by Dr. Y. Takahashi (H. Yashima) (S033)



KURRI LINAC

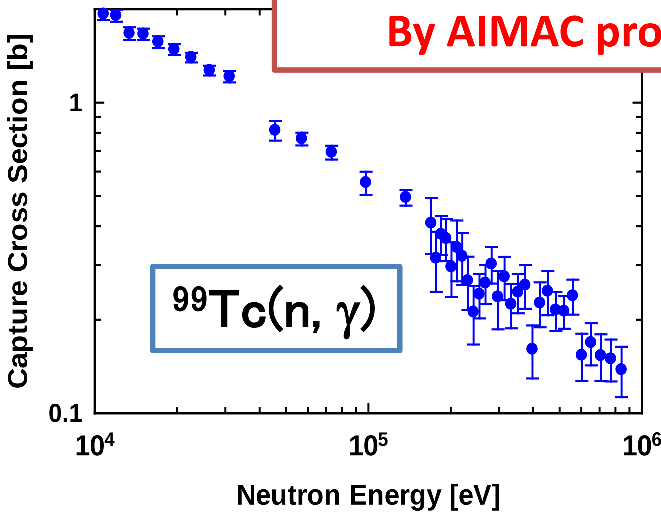
High time resolution（2～100 ns width）

Details on energy resolution by Dr. T. Sano



Note: Data of different thickness samples also enable systematic cross-check of self-shielding & scattering correction factor

④-1 New Evaluation by AIMAC

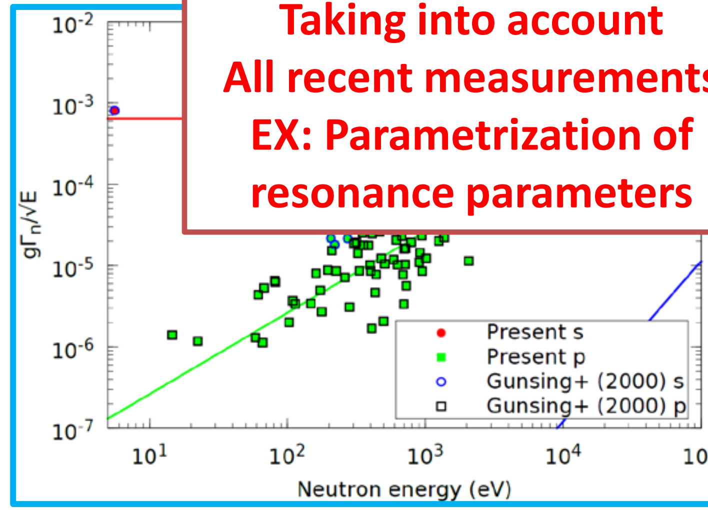


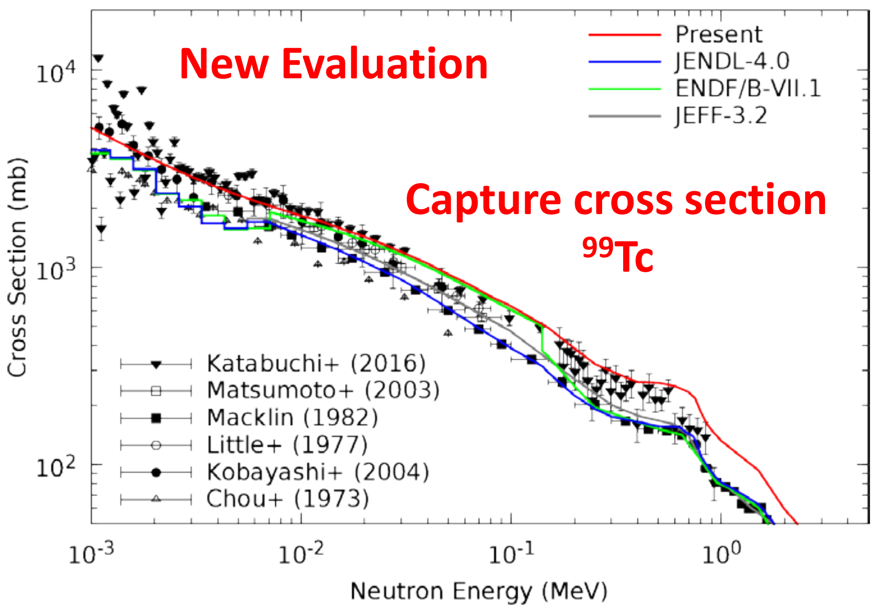
New measurement
By AIMAC project

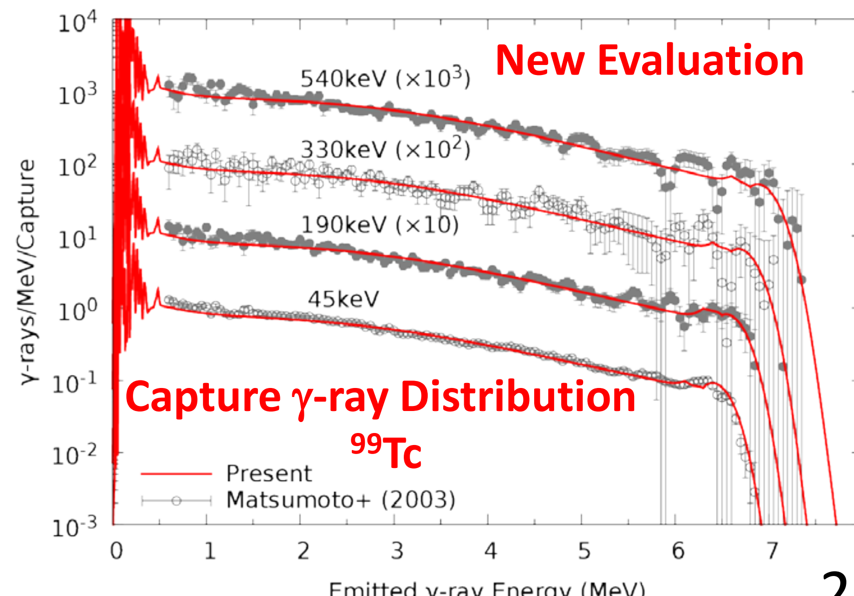
+

Details by Dr. N. Iwamoto (S185)

Taking into account
All recent measurements
EX: Parametrization of resonance parameters



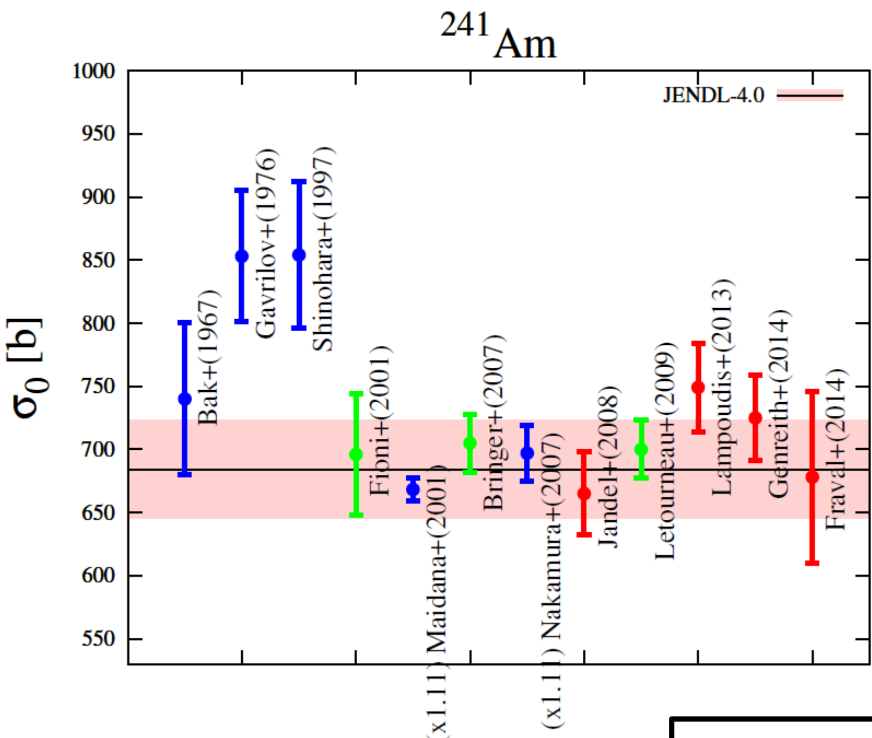


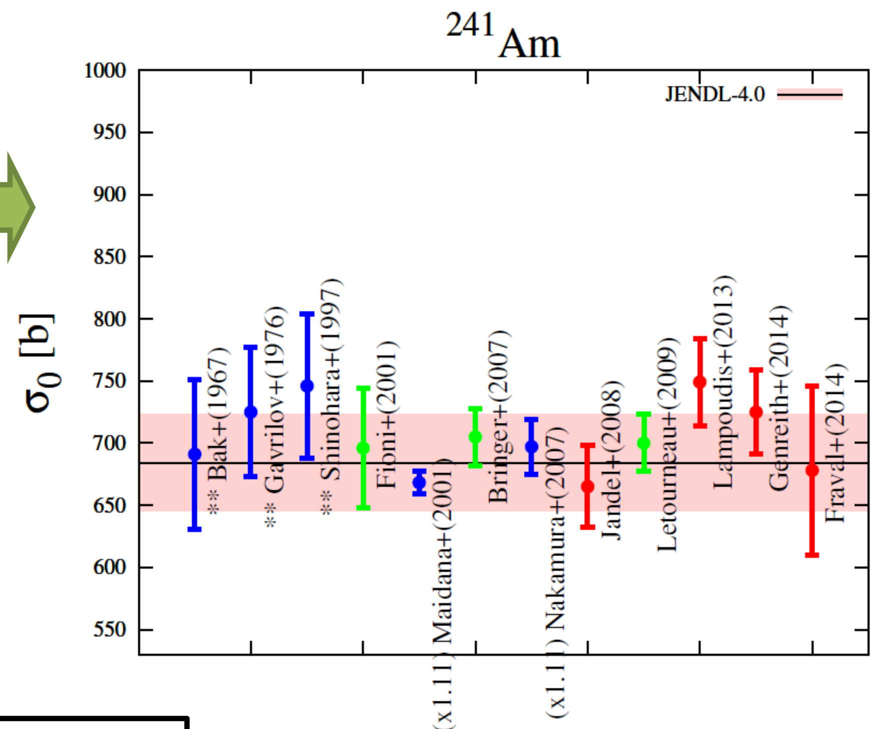


④-2 Systematic correction of bias effects

Re-evaluation of Cd ratio (Activation) data

Correction of resonance contribution below Cd cut-off energy





$$\frac{\mathrm{R}}{\sigma_0} = g\phi_1 + s_0^c\phi_2 + \delta s_0\phi_2$$

$$\delta s_0 = \frac{2}{\pi^{1/2}\sigma_0}\int_{\mu kT}^{0.5}\frac{dE}{E}\left(\sigma(E) - \sqrt{\frac{E_0}{E}}\,g\sigma_0\right)$$

K. Mizuyama, *et al.*, JNST online (2016)

Importance of identifying bias effects & systematic correction!

Conclusions

- High precision sample characterization techniques have been developed. Effectiveness of combinational use of these techniques was shown.

Micro Calorimetry

γ spectroscopy

α spectroscopy

Mass analysis TIMS

- Highlights of Activation and TOF techniques

Activation measurement technique at TOF facility

Precise decay γ-ray emission probability

Single bunch data for Am-241, Am-243 capture

Capture at ANNRI extended from 100 to 800 keV

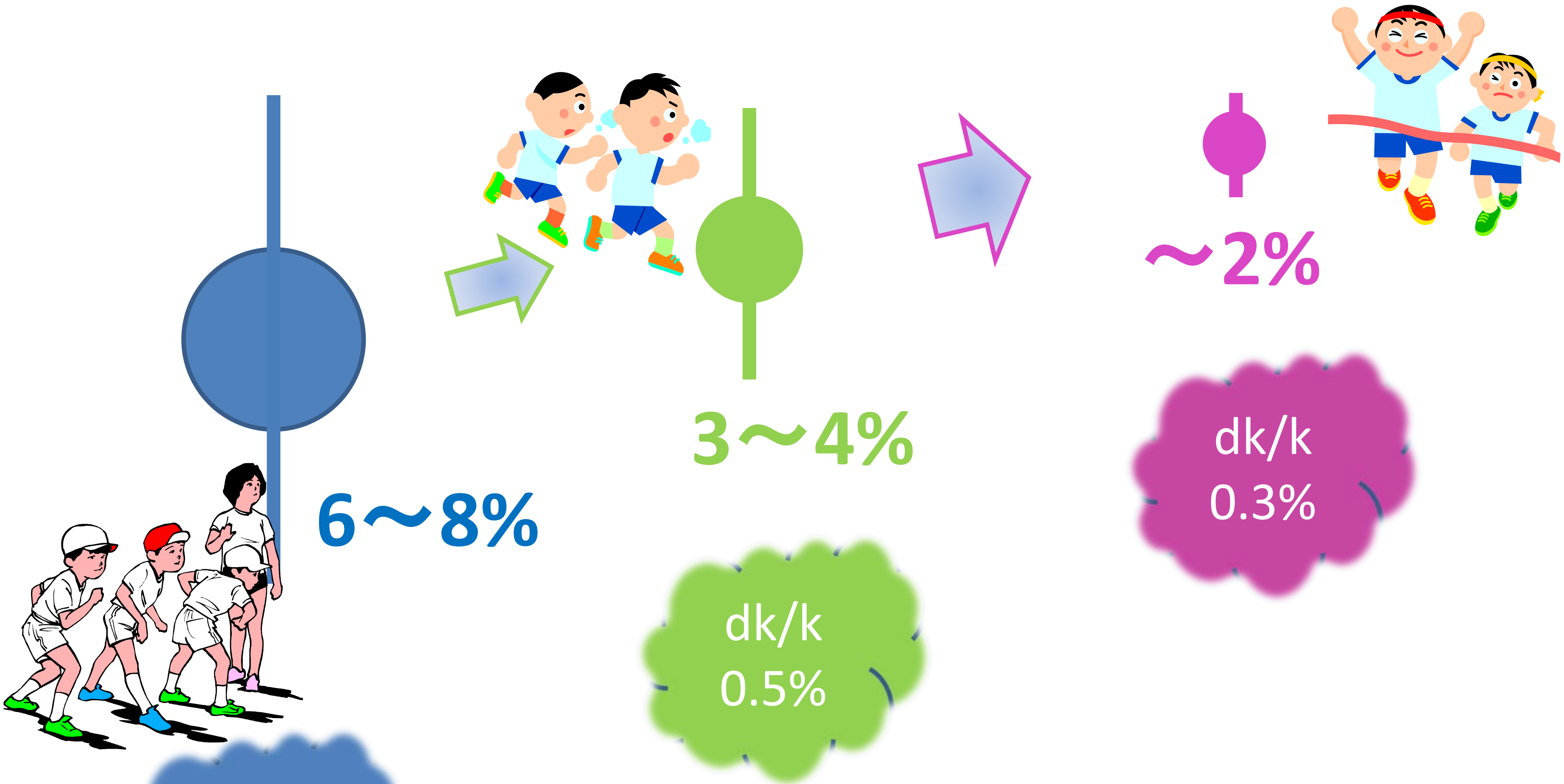
Ratio method for absolute cross section: Gd-155,157

Three different thickness sample measured for MA

The first transmission data of Am-241 at ANNRI

- Effectiveness of Re-evaluation with systematic bias effect corrections

Future Perspective



Efforts of decreasing statistical and systematic uncertainties should be encouraged, …

From JAEA-Conf 2013-002, p.51